Head movement measurement: An alternative method for posturography studies

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A B S T R A C T

The present study evaluated the measurement of head movements as a valid method for postural emotional studies using the comparison of simultaneous recording of center of pressure (COP) sway as criterion. Thirty female students viewed a set of 12 pleasant, 12 unpleasant and 12 neutral pictures from the International Affective Picture System, repeated twice, using a block presentation procedure while standing on a force platform (AMTI AccuSway). Head movements were recorded using a webcam (©KPC139E) located in the ceiling in line with the force platform and a light-emitting diode (LED) placed on the top of the head. Open source software (CvMob 3.1) was used to process the data. High indices of correlation and coherence between head and COP sway were observed. In addition, pleasant pictures, compared with unpleasant pictures, elicited greater body sway in the anterior-posterior axis, suggesting an approach response to appetitive stimuli. Thus, the measurement of head movement can be an alternative or complementary method to recording COP for studying human postural changes.

1. Introduction

Measuring the position and displacement of the center of pressure (COP) is a reliable and ecologically valid way to study postural changes. COP has been commonly used to characterize motor approach/avoidance and sensory intake/rejection processes by assessing the amount of spontaneous body sway while viewing threatening and safety stimuli. The most widely used tools for assessing postural changes include force platforms [1,2], Balance Master [3] and accelerometers [4]. These systems provide information about pressure performed on the ground, reaction forces and stabilometry. The point projection of the vertical reaction forces recorded by the platform is decomposed into two centers of pressure signals, corresponding to the anterior-posterior (AP) and medial-lateral (ML) axes of movement. The COP location is maintained by the ankles, which control the A-P axis through forward or backward corrective motion and the M-L axis through movements of adductors and abductors muscles. Consequently, COP changes over time, even when standing still [5,6].

The measurement of head movements while viewing threatening or safety stimuli could be a method to measuring postural control using force platforms. Head movements indicating approach or avoidance of visual stimuli have been directly related to sensory intake or rejection of those stimuli [7]. Moreover, early information describing the required direction for stimulus approach involves anticipatory head movements [8,9]. [10–12] studied a wide variety of locomotors tasks and postulated that the neural control of head movement plays a key role in trunk coordination to reorient the body towards goals. Previous studies have also examined spontaneous postural changes to visual stimuli using platforms systems [13–16]. Generally, previous results have indicated that the human body exhibits a small number of spontaneous postural fluctuations in the horizontal plane and that passive viewing of unpleasant pictures may elicit a significant reduction in this postural sway [16]. It has been argued that this reduction could reflect a neuromuscular response involving contraction or stiffening of the muscles around the ankle joint, suggesting the presence of a reactive freezing response to unpleasant stimuli [13,14,17]. Others studies have demonstrated that watching unpleasant pictures may elicit significant backward movement compared with pleasant [18] or neutral [19] pictures.

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Recently, [20] used a new system to evaluate changes in postural sway movements in response to the observation of painful, happy and neutral facial expressions. The results have shown that both happy and painful faces elicited greater amplitude of body sway in the anterior-posterior axes compared with neutral faces, suggesting that these stimuli may be associated with approach and cooperation rather than avoidance.

The present study aimed to compare simultaneous recording and analysis of head movements and posturography (COP) in the context of an emotional task. A classic paradigm for studying emotional modulation of postural control based on the passive viewing of pleasant, neutral and unpleasant pictures was implemented [13,21]. We hypothesized that head movements and COP would exhibit a similar pattern of movements. In addition, we hypothesized that viewing unpleasant pictures would elicit smaller postural sway than viewing pleasant pictures.

2. Method

2.1. Participants

Thirty female students aged between 18 and 25 years (M = 20.4 ± 2.3 years) were included. All participants reported no neurological, psychological or musculoskeletal disorders and were not taking medication. Participants were volunteers and were recruited at the University of Granada. They received course credit for participation. All subjects provided written informed consent, and the protocol was approved by the ethics committee at the University of Granada.

2.2. Procedure

Each subject viewed thirty-six pictures that were divided into three affective categories (12 pleasant, 12 unpleasant and 12 neutral) from the International Affective Picture System (IAPS) [22]. Pleasant pictures depicted erotic scenes, unpleasant pictures included scenes of mutilated bodies, and neutral pictures were images of household objects. Pictures were shown for three seconds without inter-stimulus intervals in a block presentation per affective category. Within each block, every picture was shown twice in random order. The duration of each block was 72 s to optimize reliability of measures according to [23]. A black background with a white fixation cross was projected for twenty seconds prior to each block. The blocks' order was counterbalanced between subjects using a Latin square procedure.

Pictures were presented using E-Prime V2.0 software on a 56" screen located at a distance of 150 cm from the participant with 38° horizontal and 34° vertical viewing angles. Participants stood on the force platform with stocking feet and adopted a comfortable natural stance with their arms relaxed along the body and their feet slightly separated (approximately 5 cm apart). A webcam located on the ceiling in vertical line with the force platform and an electronic LED diode placed on the top of the head were used to record the head movements. The task was performed in a small and dimly lit room.

When participants finished the experiment, they moved to another room to evaluate the valence and arousal of the displayed pictures on a tactile-screen computer using the Self-Assessment Manikin (SAM; [24]. The SAM is a non-verbal pictorial assessment technique that measures the subjective pleasure and activation associated with a person's affective reaction to a wide variety of stimuli. Each SAM scale is represented by five humanoid figures (and four intervals between figures) ranging from a frowning face to a smiling face (for the valence dimension) and from a sleepy-looking face to an agitated figure (for the arousal dimension). The ratings were converted to numbers ranging from 1 (lower extreme) to 9 (upper extreme).

2.3. Video recording and data acquisition

Head movement was recorded with a standard webcam (©KPC139E) located above the head of the participant at a mean distance of 50 cm. The webcam recorded 25 frames per second at a 640 × 480 resolution (pixels size = 0.73 mm). Data were processed using open source software (CvMob 3.1, http://www.cvmob.ufba.br/) developed for computer vision purposes [20,25–27]. Calibration of the CvMob 3.1 was performed using a LED diode and an adhesive dot as reference markers placed on the top of the participant's head with a 5 cm separation. The software was able to extract indices of trajectory in 'x' and 'y' axes by the optical flow generated with the postural adjustments.

The COP was collected through the AMTI AccuSway (Advanced Mechanical Technology, Inc., Watertown, MA) force platform consisting of a square aluminum plate (width 50 × 50 cm; weight 11.4 kg; height: 14.4 cm) combined with AMTI software. The software was able to decompose the vertical reaction forces into two COP signals, one for the AP axis movement and the other for the ML axis movement, recorded at 50 Hz.

Data were synchronized between the CvMob and AMTI AccuSway using E-Prime V2.0 software. At the beginning of the trial, a digital input was sent to switch on the LED diode and to the force platform simultaneously, in order to synchronize both data recordings. Then, head movement and COP data were processed off-line using Matlab software (MathWorks Inc., MA). To obtain two comparable signals and check for coherence between COP and head movement, the platform signal was resampled to 25 Hz. Pearson correlation between both signals during the whole recording period −7400 frames, including the three blocks with their baseline- was calculated within subjects in AP and ML axis. Similarly, the signals' coherence during the whole recording period was defined for each subject as the mean and standard deviation of the difference between both signals from normalized-transformed data, providing a coherence index between 0 (high) and 1 (low). In order to obtain a rigorous description of the relationships between the COP sway and the head sway, a cross-spectral analysis was performance for each affective block (pleasant, neutral and unpleasant) in both axes (ML and AP).

2.4. COP and head movement parameters

Responses to affective pictures were calculated from COP and the head movement. The signal during each block was rectified by subtracting the mean sway of one second prior to each emotional block for the AP and ML axes. Then, the following parameters for both axes were obtained: *body sway*, defined as the mean of standard deviation displacement in each affective block; *total displacement of sway*, defined as the length of the COP or head movement trajectory while the participant viewed the affective pictures; *mean distance of sway*, defined as the mean of distance between COP or head and screen in each affective block; and *mean frequency of head movement*, defined as the power spectral density of the signal estimated using fast Fourier transformation, with a resolution of 0.01 Hz, and then averaged in 10 frequency intervals between 0.1 Hz and 1 Hz.

2.5. Statistical analysis

Subjective and body sway data were initially checked for normal distribution using the Shapiro-Wilk test. Our datasets had a significantly normal distribution. Valence/arousal ratings and postural measures (body sway and total displacement of sway) were analyzed separately using one-way repeated measures analysis of variance (ANOVAs) with emotion (pleasant, unpleasant and neutral category) as a within-subjects factor. For the mean frequency of COP and head movement, a second repeated measures factor (the 10 frequency intervals) was added. The correlation and coherence indices for the whole sample were calculated by averaging the individual indices. In order to quantify the cross-coherence between COP and head movement on frequency changes, frequency spectra were split into ten bins of 0.1 Hz, from 0.1 to 1 Hz. We excluded frequencies above 1 Hz based of fast Fourier analysis results, which indicated that movement was concentrated bellow 1 Hz. We followed the method of surrogate data testing [39] to assess cross-coherence between COP and head movement. Firstly cross-coherence between COP and head movement was computed for each frecuency of series of data to each emotion. After, 1000 surrogate data sets were generated with original data sets and compared with real cross-coherence value to each bin.

All analyses were performed with the SPSS statistical package. Greenhouse-Geyser epsilon corrections were applied when necessary, and post-hoc pair wise comparisons were performed using Holm test correction. A significance level of 0.05 was used for all statistical analyses.

3. Results

3.1. Subjective ratings

The average ratings of the IAPS images were similar to those obtained from the Spanish reference norms for pleasant (valence: mean = 7.1, SD = 0.19; arousal: mean = 5.7, SD = 0.45), neutral (valence: mean = 5.2, SD = 0.21; arousal: mean = 2.5, SD = 0.18) and unpleasant images (valence: mean = 1.9, SD = 0.24; arousal: mean = 6.2, SD = 0.3). The ANOVA on valence and arousal ratings revealed a significant effect of category for both the valence and arousal dimensions ($p < 0.001$). Post hoc comparisons indicated that valence ratings for pleasant pictures were significantly higher than those for neutral pictures and unpleasant pictures (all $p < 0.001$). Unpleasant pictures were significantly lower than those for neutral ones ($p < 0.001$). Unpleasant pictures were rated as more arousing than both neutral pictures ($p < 0.001$) and pleasant pictures ($p < 0.001$). Pleasant pictures were also more arousing than neutral pictures ($p < 0.001$).

3.2. Correlation and coherence between signals

The COP and head movement signals during the whole recording time produced similar results. Fig. 1 shows the plot of COP and head movement of a representative subject in the AP and ML axes. Pearson correlation coefficients between COP and head movement indicated significant correlations for each subject, ranging from 0.32 ($p < 0.001$) to 0.96 ($p < 0.001$). The average correlation of all subjects was 0.82 in the AP axis and 0.73 in the ML axis.

The coherence indices (mean and standard deviation difference [SDD]) between COP and head movements revealed values near 0 for each subject in both axes, ranging from 0.0462 (SDD = 0.0136) to 0.0099 (SDD = 0.0043) in the AP axis and from 0.0549 (SDD = 0.013) to 0.0117 (SDD = 0.0038) in the ML axis (Fig. 2). The average coherence index of mean difference was 0.0011 in the AP axis and 0.0008 in the ML axis. The average coherence index of standard deviation difference was 0.0084 in the AP axis and 0.0091 in the ML axis.

Cross-coherence was calculated between COP and head movements for each affective block in ML and AP axes (Fig. 3). The dashed line shows the upper level of the 95% confidence interval for the hypothesis that the two measures are independent. There was a very high degree of cross-coherence between COP and head movement at all frequency bins and all affective categories to ML and AP axes.

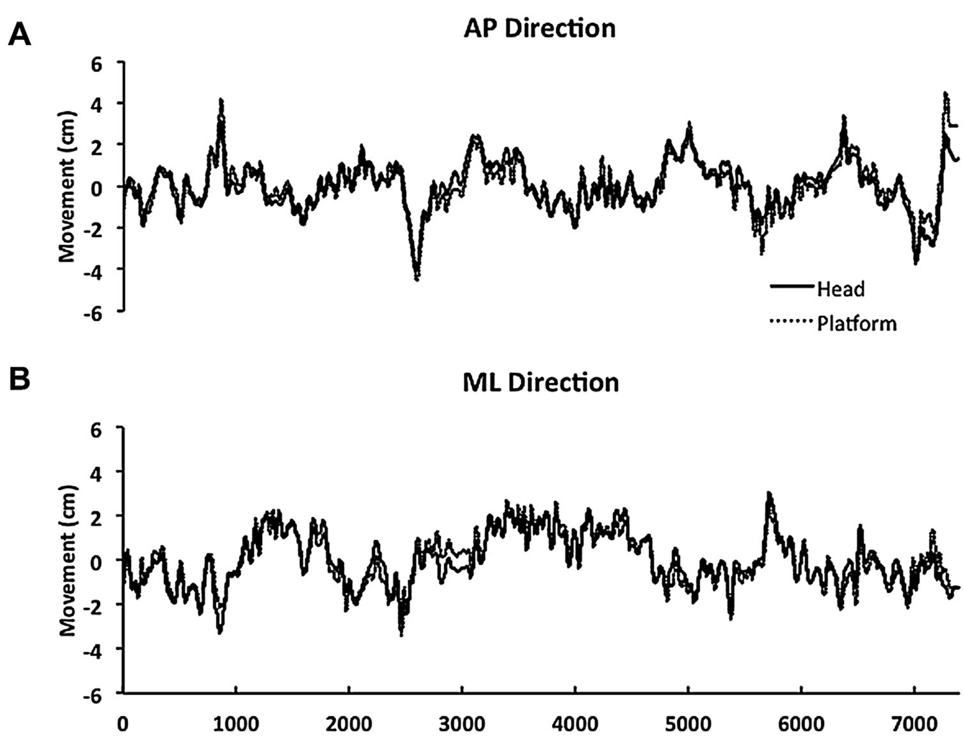

Fig. 1. Plot of a representative participant showing strong correlation between COP and head movement during the whole recording time in the AP (a) and ML (b) axes.

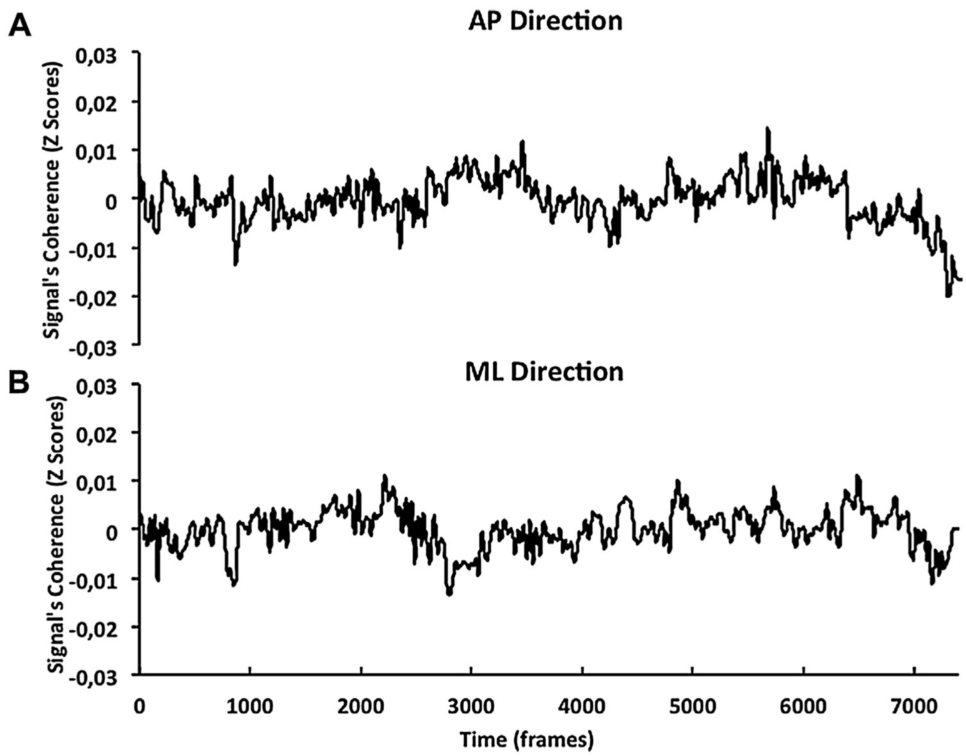

Fig. 2. Coherence between COP and head movement. The plot shows the mean for all subjects of the difference between COP and head movement from normalized signals over the whole recording time in the AP (a) and ML (b) axes. Coherence index ranges from 0 (high) to 1 (low).

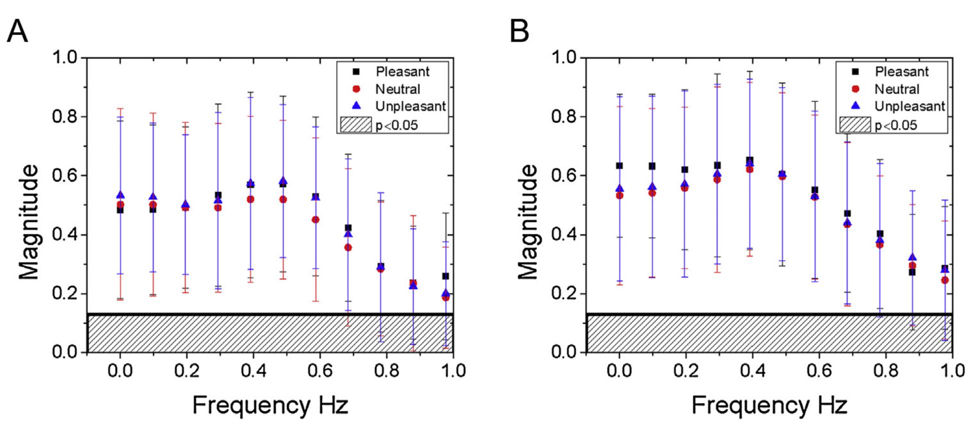

Fig. 3. Cross-coherence between COP and head movement. The plot shows the mean for all subjects of the difference between COP and head movement from normalized signals for each category in the AP (a) and ML (b) axes. The dashed line shows the upper level of the 95% confidence interval for the hypothesis that the two measures are independent.

3.3. Posturography parameters

3.3.1. Body sway

A repeated measures ANOVA of COP body sway, with emotion (pleasant, neutral and unpleasant category) as a within-subjects factor, revealed a main effect in the AP axis ($F\ (1{,}29) = 3.568$, $p < 0.035$). Unpleasant pictures induced a decrease in standard deviation ($p < 0.040$) in the AP axis relative to pleasant pictures. Neutral pictures did not show any significant difference with regard to pleasant or unpleasant pictures. A main effect for emotion was also observed for head movement in the AP axis ($F\ (1{,}29) = 3.642$, $p < 0.034$), with a decreased standard deviation during the unpleasant pictures ($p < 0.046$) compared to the pleasant pictures (Fig. 4). No significant differences were found for neutral pictures in COP and head movement. We did not find a significant emotion modulation effect in the ML axis for COP ($F\ (1{,}29) = 0.201$, $p < 0.798$) or head movement ($F\ (1{,}29) = 0.389$, $p < 0.655$).

3.3.2. Total displacement of sway

The analysis of variance with emotion (pleasant, neutral and unpleasant) as a within-subjects factor showed no significant effects for the COP total displacement of sway during visualization of pictures ($F\ (2{,}29) = 0.079$ ($p < 0.890$) or for head movement ($F\ (2{,}29) = 0.034$ ($p < 0.956$). All affective categories elicited the same displacement in both measures. No significant differences were observed in the ML axis.

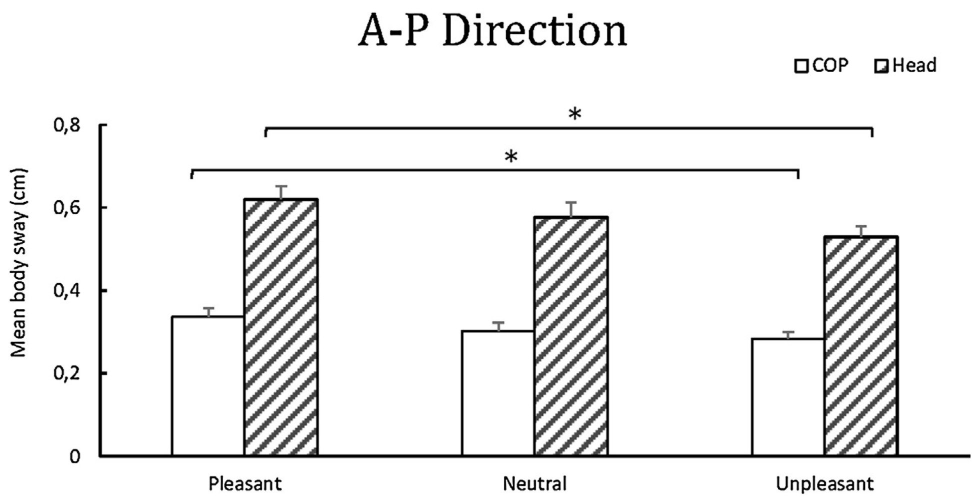

Fig. 4. Mean body sway for pleasant, neutral and unpleasant picture blocks. Movement is expressed in standard deviation from participants' center of head movement in the AP direction. Error bars represent standard errors. Asterisks indicate significant differences between stimulus categories (*$p < 0.05$).

3.3.3. Mean distance of sway

A repeated measures ANOVA of COP mean distance of sway, with emotion (pleasant, neutral and unpleasant category) as a within-subjects factor, showed a significant main effect of emotion ($F\ (1,29) = 3.896$, $p < 0.037$). Pairwise comparison did not reach significant differences between affective blocks (all $p > 0.05$). The analysis of variance for head movement also yielded a significance effect of emotion ($F\ (1,29) = 6.145$, $p < 0.004$). Furthermore, pairwise comparisons revealed a marginally significant mean distance of sway during pleasant blocks compared to neutral blocks ($p < 0.07$). Not significant differences were found for the rest of the emotional blocks.

3.3.4. Mean frequency of head movement (mean power frequency)

The 3×10 ANOVA (emotion x frequency interval) for COP indicated significant effects of emotion in the AP direction ($F\ (2,58) = 3.673$, $p < 0.039$) and frequency interval ($F\ (9,261) = 148.147$, $p < 0.01$). The interaction did not reach statistical significance ($F\ (18,522) = 2.417$, $p < 0.102$). Post-hoc comparisons revealed that viewing unpleasant pictures increased the mean power frequency ($p < 0.037$) in the AP direction compared with neutral pictures. No significant differences were found between neutral and pleasant or pleasant and unpleasant pictures. A similar analysis of variance for head movement showed a main significant effect of emotion in the AP direction ($F\ (2,58) = 4.350$, $p < 0.05$), frequency interval ($F\ (9,261) = 89.279$, $p < 0.01$) and the interaction ($F\ (18,522) = 4.631$, $p < 0.01$). Post-hoc comparisons indicated an increased mean power frequency in the AP direction during the pleasant pictures visualization ($p < 0.005$) with respect to unpleasant and neutral pictures (Fig. 5), but only in the very low frequencies (0.1 Hz and 0.2 Hz) (all $p < 0.05$). Neutral and unpleasant pictures did not show significant differences. No significant effects were found in the ML direction for COP neither for head movement.

4. Discussion

This study aimed to evaluate head movements as a valid measure for postural control studies using comparisons of the simultaneous recording of center of pressure movements as a criterion. High associations between head and center of pressure sway in the anterior-posterior and medial-lateral axes were observed. In addition, viewing pleasant pictures elicited a greater body sway in both, COP and head movement, in the anterior-posterior axis compared with viewing unpleasant pictures. Similar results were found for mean distance of sway, but just for the head movement measurement, with a reduced mean distance during the pleasant block in comparison with the neutral block. The mean

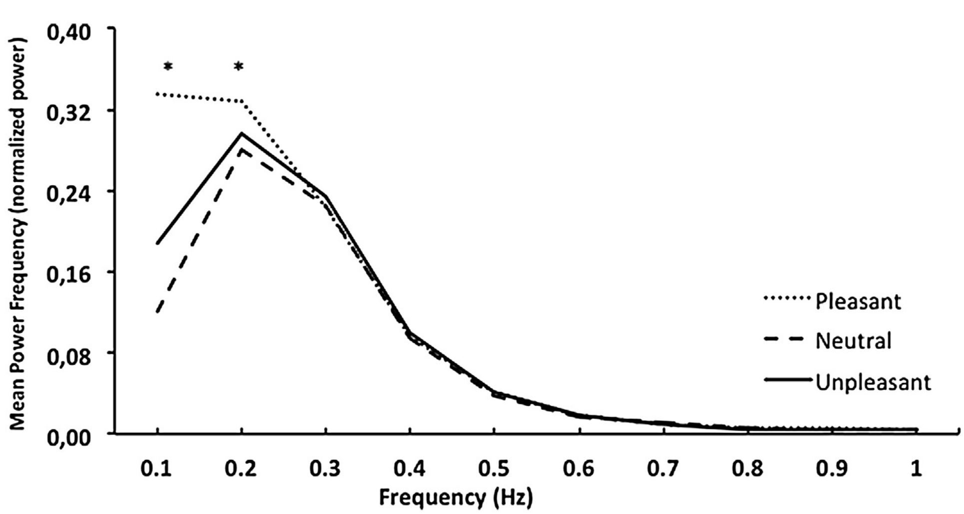

Fig. 5. Spectrum of power frequency of head movement in 10 frequency intervals (0.1–1 Hz) for pleasant, neutral and unpleasant picture blocks.

power frequency of head movement in the lower frequencies was also greater for pleasant pictures than unpleasant pictures. As expected, valence and arousal ratings indicated high arousal and valence scores for pleasant pictures and high arousal and low valence scores for unpleasant pictures compared with neutral pictures.

Our results revealed high correlation and coherence between head and COP movements and frequencies, indicating that the measurement of head movement while viewing visual stimuli could be an alternative method to COP platform systems to evaluate avoidance and approach behaviors [8,9]. Platforms pressure systems have been considered the standard instrument for measuring postural sway [28]. However, they are often expensive, difficult to implement and unreliable regarding the detection of small postural changes [29,30]. Because the human head is considered to play a key role controlling balance, head movement measurement is an interesting new method for postural control studies. These data reflect that there is a strong relationship between head movements and postural control, as has been observed in previous studies [8,9]. [10–12] suggested that head placement and stabilization provide a stationary frame of reference (an "inertial guidance platform") for the coordination of many body segments. Postural control depends on the integration of information from different groups of receptors around the head, reflecting the dynamics of perception and action related to movement regulation [31–34]. As expected, the cross-spectral analysis showed considerable coherence between COP and head sway for each condition during quiet standing postural task. The strong correlations observed here between head movement and COP confirm the role of the head as a key component for body stabilization and equilibrium.

We also found that pleasant pictures elicited greater body sway and greater mean power in lower frequencies in the A-P direction compared with unpleasant pictures. Moreover, the mean distance of sway with respect to display during pleasant blocks showed a reduction regard to the neutral block. These results support partially the biphasic theory of emotion [36,37], which suggests that emotion is organized around two motivational systems: appetitive and defensive [38]. The appetitive system is responsible for approach behaviors and involves preservative actions that underlie pleasant reactions [35]. The defensive system is responsible for withdrawal or avoidance behavior that is activated in the context of threat and underlies unpleasant reactions [35]. These two systems are mediated by brain circuits that have evolved to organize behavior for the purpose of survival [38]. The increased body sway, the reduction of distance between head and display and the greater mean power frequency in the pleasant block, seem to indicate the presence of an approach response to pleasant pictures, which is coherent with the appetitive system proposed by Lang [36,37]. By contrast, unpleasant pictures did not show differences with regard to neutral pictures in body sway, mean distance of sway and mean frequency of head movement. These findings are in disagreement with previous posturographic research data on postural sway and body movement which showed that threat stimuli may induce a "freezing" behavioral reaction [13,14] or reduced sway [20,16].

The relevance of our findings should be evaluated considering some methodological limitations. Firstly, we did not include a resting period between emotional blocks in order to control stance position between categories. Second, we recorded head movement with a low velocity camera, and our sampling rate was lower than that of traditional systems. Third, we measured only two types of body movement (COP and head) and interpreted them as indicators of an appetitive/defensive reaction, when this type of motor behavior is the result of the combination of many body movements. Further investigations should record movement from other body parts related to defensive reactions and postural control. Finally, our participants were all female, limiting the generalizability of our findings.

Considering these limitations, our study demonstrates that recording head movement can be an alternative method to recording COP for studying human postural changes. The measurement of head movements can be particularly useful in the context of examining postural control during the processing of threatening and safety stimuli. In addition, this information can be useful for researchers and clinicians to understand the basis of postural control and develop new training and intervention programs to help individuals with balance disorders.

References

[1] H.G. Palm, P. Lang, J. Strobel, H.J. Riesner, B. Friemert, Computerized dynamic posturography: the influence of platform stability on postural control, Am. J. Phys. Med. Rehabil. 93 (1) (2014) 49–55.
[2] J.M. Leach, M. Mancini, R.J. Peterka, T.L. Hayes, F.B. Horak, Validating and calibrating the nintendo wii balance board to derive reliable center of pressure measures, Sensors 14 (10) (2014) 18244–18267.
[3] F.Y. Cheng, Y.R. Yang, C.J. Wang, Y.R. Wu, S.J. Cheng, H.C. Wang, R.Y. Wang, Factors influencing turning and its relationship with falls in individuals with Parkinson's disease, PLoS One 9 (4) (2014) e93572.
[4] S.L. Whitney, J.L. Roche, G.F. Marchetti, C.C. Lin, D.P. Steed, G.R. Furman, M.S. Redfern, A comparison of accelerometry and center of pressure measures during computerized dynamic posturography: a measure of balance, Gait Posture 33 (4) (2011) 594–599.
[5] D.A. Winter, Human balance and posture control during standing and walking, Gait Posture 3 (4) (1995) 193–214.
[6] D.A. Winter, F. Prince, J.S. Frank, C. Powell, K.F. Zabjek, Unified theory regarding A/P and M/L balance in quiet stance, J. Neurophysiol. 75 (6) (1996) 2334–2343.
[7] S.R. Arnott, C. Alain, The auditory dorsal pathway: orienting vision, Neurosci. Biobehav. Rev. 35 (10) (2011) 2162–2173.
[8] M. Hollands, K. Sorensen, A. Patla, Effects of head immobilization on the coordination and control of head and body reorientation and translation during steering, Exp. Brain Res. 140 (2) (2001) 223–233.
[9] R. Grasso, P. Prévost, Y.P. Ivanenko, A. Berthoz, Eye-head coordination for the steering of locomotion in humans: an anticipatory synergy, Neurosci. Lett. 253 (2) (1998) 115–118.
[10] T. Pozzo, A. Berthoz, L. Lefort, Head stabilization during various locomotor tasks in humans, Exp. Brain Res. 82 (1) (1990) 97–106.
[11] T. Pozzo, Y. Levik, A. Berthoz, Head stabilization in the frontal plane during complex equilibrium tasks in humans, Posture and Gait: Control Mechanisms, University of Oregon Books, Eugene OR, 1992, pp. 118–121.
[12] T. Pozzo, Y. Levik, A. Berthoz, Head and trunk movements in the frontal plane during complex dynamic equilibrium tasks in humans, Exp. Brain Res. 106 (2) (1995) 327–338.
[13] T.M. Azevedo, E. Volchan, L.A. Imbiriba, E.C. Rodrigues, J.M. Oliveira, L.F. Oliveira, C.D. Vargas, A freezing-like posture to pictures of mutilation, Psychophysiology 42 (3) (2005) 255–260.
[14] L.D. Facchinetti, L.A. Imbiriba, T.M. Azevedo, C.D. Vargas, E. Volchan, Postural modulation induced by pictures depicting prosocial or dangerous contexts, Neurosci. Lett. 410 (1) (2006) 52–56.
[15] F.L. Lopes, T.M. Azevedo, L.A. Imbiriba, R.C. Freire, A.M. Valença, D. Caldirola, A. E. Nardi, Freezing reaction in panic disorder patients associated with anticipatory anxiety, Depress. Anxiety 26 (10) (2009) 917–921.
[16] K. Roelofs, M.A. Hagenaars, J. Stins, Facing freeze: social threat induces bodily freeze in humans, Psychol. Sci. 21 (11) (2010) 1575–1581.
[17] J.F. Stins, P.J. Beek, Effects of affective picture viewing on postural control, BMC Neurosci. 8 (1) (2007) 83.
[18] C.H. Hillman, K.S. Rosengren, D.P. Smith, Emotion and motivated behavior: postural adjustments to affective picture viewing, Biol. Psychol. 66 (1) (2004) 51–62.
[19] M.I. Vousdoukas, P. Perakakis, S. Idrissi, J. Vila, SVMT: A MATLAB toolbox for stereo-vision motion tracking of motor reactivity, Comput. Methods Programs Biomed. 108 (1) (2012) 318–329.
[20] J. Gea, M.A. Muñoz, I. Costa, L.F. Ciria, J.G. Miranda, P. Montoya, Viewing pain and happy faces elicited similar changes in postural body sway, PLoS One 9 (8) (2014) e104381.
[21] M.M. Bradley, P.J. Lang, Emotion and motivation, in: J.T. Cacioppo, L.G. Tassinary, G. Berntson (Eds.), Handbook of Psychophysiology, 3rd ed., Cambridge University Press, New York, 2007, pp. 581–607.
[22] P.J. Lang, M.M. Bradley, B.N. Cuthbert, The center for research in psychophysiology, International Affective Picture System (IAPS): Instruction Manual and Affective Ratings, University of Florida, 1999.
[23] M.G. Carpenter, J.S. Frank, C.P. Silcher, G.W. Peysar, The influence of postural threat on the control of upright stance, Exp. Brain Res. 138 (2) (2001) 210–218.
[24] M.M. Bradley, P.J. Lang, Measuring emotion: the self-assessment manikin and the semantic differential, J. Behav. Ther. Exp. Psychiatry 25 (1) (1994) 49–59.

[25] N. Pena, B.L. Credidio, F.L. Correa BCAl, L.G.S. Cunha, Instrumento livre para medidas de movimento, Revista Brasileira de Ensino de Fısica 35 (3) (2013) 3505.
[26] A. Babin, S. Kolly, T.J. Kawecki, Virulent bacterial infection improves aversive learning performance in Drosophila melanogaster, Brain Behav. Immun. 41 (2014) 152–161.
[27] B. Hollis, T.J. Kawecki, Male cognitive performance declines in the absence of sexual selection, Proc. R. Soc. Lond. B Biol. Sci. 281 (1781) (2014) 20132873.
[28] B.M. Haas, A.M. Burden, Validity of weight distribution and sway measurements of the balance performance monitor, Physiother. Res. Int. 5 (1) (2000) 19–32.
[29] U. Lindemann, R. Moe-Nilssen, S.E. Nicolai, C. Becker, L. Chiari, Assessment of balance in unsupported standing with elderly inpatients by force plate and accelerometers, Aging Clin. Exp. Res. 24 (1) (2012) 37–41.
[30] H. Chaudhry, B. Bukiet, Z. Ji, T. Findley, Measurement of balance in computer posturography: comparison of methods—a brief review, J. Bodyw. Mov. Ther. 15 (1) (2011) 82–91.
[31] B. Isableu, T. Ohlmann, J. Crémieux, B. Amblard, Selection of spatial frame of reference and postural control variability, Exp. Brain Res. 114 (3) (1997) 584–589.
[33] T. Kanaya, M.A. Gresty, A.M. Bronstein, D. Buckwell, B. Day, Control of the head in response to tilt of the body in normal and labyrinthine-defective human subjects, J. Physiol. 489 (Pt 3) (1995) 895–910.
[34] A.M. Bronstein, Evidence for a vestibular input contributing to dynamic head stabilization in man, Acta Otolaryngologica 105 (1–2) (1988) 1–6.
[35] M.M. Bradley, P.J. Lang, Emotion and motivation, Handb. Psychophysiol. 2 (2000) 602–642.
[36] P.J. Lang, The emotion probe: studies of motivation and attention, Am. Psychol. 50 (5) (1995) 372.
[37] P.J. Lang, M.M. Bradley, B.N. Cuthbert, Motivated attention: affect, activation, and action, Atten. Orienting Sens. Motivational Processes (1997) 97–135.
[38] P.J. Lang, M. Davis, A. Öhman, Fear and anxiety: animal models and human cognitive psychophysiology, J. Affect. Disorders 61 (3) (2000) 137–159.
[39] M.B. Kennel, S. Isabelle, Method to distinguish possible chaos from colored noise and to determine embedding parameters, Phys. Rev. A 46 (6) (1992) 3111.